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Genetically Modified Organisms (GMOs)
And the Potential Impact on Army Operations

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Submitted to:

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In fulfillment of an on-site US Army Reserve Annual Training Assignment
15-28 Sep 02

Abstract:

Genetically modified organisms (GMO), are increasing in numbers, applications and controversy. This short paper explores the environmental implications of genetically modified plants with respect to the Army mission. To do so, the author summarizes scientific and political issues and suggests some opportunities and threats that could lie ahead. While GMOs hold potential for great benefits to mankind, the unknown risks are obviously unfathomed and intentional "weaponization" could pose subtle, but powerful, threats to trade and political stability. GMOs could also be developed to serve as sensors for military contaminants in the environment.

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INTRODUCTION

A genetically modified organism (GMO) is defined by the European Union as an organism in which the genetic material has been altered in a way that does not occur naturally by mating and/or natural recombination [1]. Typically this entails the insertion of a gene or genes from one organism into another in order to impart some desirable characteristic in the transformed organism. Advances in our understanding of gene regulation and metabolic pathways also portend the ability to alter the metabolism of plants and animals through antisense RNA and RNA interference mechanisms to enhance the production of desirable metabolites without introduction of foreign DNA. The potential benefits for mankind stemming from GMOs are seemingly limitless. Agricultural crops with built-in insecticides and enhanced herbicide resistance are now a reality. A beta-carotene (provitamin A) producing cultivar of rice has been bio-engineered [2]. Vitamin A deficiency results in blindness for hundreds of thousands of children each year in Southeast Asia; this new GMO offers the potential to curb this nutritionally based scourge. Indeed, while first generation GMO crops have focused on "input" technologies, i.e. imparting traits to protect the plants such as pest resistance, the next generation of GMO will likely focus more on "output" technologies, i.e. production of crops with added nutritional characteristics such as vitamins, anti-oxidants, enhanced protein or energy content as well as the large scale production of proteins and enzymes for pharmacological and industrial application.

GMO crops such as corn, soybeans and cotton enjoy widespread popularity in the agricultural communities of the United States, Canada, Argentina and China and have, for the most part, been routinely accepted by consumers in these countries. In other parts of the world, particularly in the European Union, public acceptance of GMO foods is very low; this dichotomy has resulted in severe trade restrictions. The reasons for this disparity in public perception and acceptance of GMOs involves a complex combination of ideology and public awareness of perceived threats, both real and imagined. In many European countries, food is a revered part of the culture with concomitant interest in the composition and healthfulness of the food source. There is also a lack of trust and confidence in governmental agencies charged with protecting the public food supply. The outbreak of hoof and mouth disease in the cattle herds of Europe along with the discovery of mad cow disease and the recognition of its transmissibility to humans has exacerbated this situation in recent years. The popular press in Europe has also been more effective at evoking public concern over environmental issues related to GMOs. Principal among these is the fear that herbicide and pest resistance traits will be transferred to other plant species resulting in "superweeds" that are impossible to control with conventional methods, or that insect pests will develop tolerance to the Bt toxin employed in some commercially available GMO crops. Another fear is that non-native proteins produced in recombinant plants might inadvertently elicit serious allergic responses in unsuspecting consumers [3].

Current legislation in the EU related to GMOs has essentially resulted in a moratorium on the utilization of GMO products. Directive 90/220/EEC, entered into force in 1991, is the main legislation that regulates release of GMOs in the Community; an updated Directive 2001/18/EC took effect on 17 Oct 2002. Regulation (EC) 258/97 on Novel Foods and Novel Food Products sets out rules for authorization and labeling of

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foods produced from GMOs. Under these guidelines no food products containing GMOs are currently authorized in the European Union.

CURRENT APPLICATION OF BIOTECHNOLOGY IN AGRICULTURE

Presently there are two principal biotechnologies being applied to crops; (1) transformation with a gene or genes that produce an insecticidal (protein) toxin isolated from the bacterium *Bacillus thuringiensis* or Bt toxin and (2) transformation with a bacterial gene encoding 5-enolpyruvylskikimate-3-phosphate synthase (EPSPS) which, unlike plant versions of this enzyme, is not inhibited by the broad spectrum herbicide glyphosate ("Round-up") [3]. Crops transformed with Bt provide the plant with a built-in insecticide and in theory reduces the requirement for synthetic pesticide application. Glyphosate resistant plants allow application of the herbicide to the growing plant thus allowing application of this popular weed control agent at times in the crop's growth cycle when it is most effective and, in theory, reducing the total amount necessary for effective mitigation of noxious weeds.

In 2001 the percentage of the major bioengineered crops worldwide were corn (63%), soybean (19%), cotton (13%) and rapeseed (canola, 5%) [4]. In 1999 the US accounted for 72% of the land planted with GM plants worldwide [5]. In 2002, in the US, 32% of the corn acreage, 71% of the cotton acreage and 74% of the soybean acreage was in GM plants [6]. Since the first introduction of GM crops in the mid-90s there is a very clear trend toward increased use of these plants worldwide [7].

The early acceptance of GM crops in the US is merely a harbinger of future developments. Bioengineered plants are being developed to produce pharmaceutical agents such as a hepatitis B vaccine by Prodigene in College Station, TX, and antibodies ("plantibodies") effective against caries (tooth decay) causing bacteria [8,9]. Production of pharmaceuticals in plants offers a number of advantages compared to isolation of these compounds from animal sources including lower cost and less risk of contamination with transmissible diseases. The potential utility of bioengineered plants is limited only by the imagination. It is entirely possible that future developments could include plants that glow when grown in the presence of explosives (for use in detecting land mines or unexploded ordinance) or plants that selectively sequester environmental contaminates, allowing the remediation of contaminated soils [10].

POTENTIAL RISKS, STARLINK A CASE STUDY

Opponents to the introduction of GMOs suggest several doomsday scenarios in which local and regional ecosystems might be catastrophically disrupted. The use of Bt toxin constitutively expressed in crops could accelerate tolerance development in otherwise susceptible insects. This would prove disastrous for many farmers that use this natural insecticide as a spray on application to control pests. This is particularly true in the organic farming community. Conversely, there is a fear that other insect varieties might be inadvertently affected by the indiscriminate production of Bt toxin. A recent study by a group from Cornell demonstrated toxic effects on monarch butterfly larvae fed milkweed impregnated with Bt corn pollen [11]. Although the validity of this study with respect to natural conditions is highly questionable and has, in fact, been largely discredited [12,13], it nevertheless resulted in heightened reservations by the public regarding the use of GMOs. There is also a concern that cross-pollination to weedy species might render them less vulnerable to natural pressures hence more noxious to agricultural operations. The prospect of outcrossing of transgenic plants to weeds is particularly troublesome with respect to the glyphosate resistant GMOs that could result in a true superweed recalcitrant to standard weed control methods.

These concerns are not without some field evidence. In 2001 investigators from the University of California Department of Environmental Science, Policy and Management detected transgenic DNA in traditional races of maize in Mexico [14]. These apparently cross-pollinated corn stocks were identified two years after a moratorium on the planting of GMO corn was enacted in Mexico and at locations many miles from any possible source of previous transgenic corn planting. However, the scientific validity of this report has been severely criticized [15].

A variety of genetically modified corn termed StarLink containing a Bt toxin from the *cry*9A gene received USDA/FDA approval for commercial sale for use as animal feed but not for human consumption (due to uncertainties concerning the allergenicity of the gene product). (Cry9A is a different form of the Bt toxins than those already approved for human consumption.) StarLink seed was sown in approximately 1% of the corn crop in Iowa in 2000. Traces of the Cry9A protein were subsequently discovered in taco shells and other commercial food items. Eventually it was estimated that as much as 50% of the corn crop in Iowa was contaminated by StarLink. The reason for this dramatic spread is still not entirely clear. There were apparently cases of mixing with non-GMO corn during transport and storage. In addition another seed company, Garst Seed, also distributed a corn hybrid containing Cry9A produced in 1998. How this occurred in not known, however much of this corn seed may have been unknowingly sold as a non-GMO seed. There is also speculation that some of the StarLink corn planted in 2000 may have pollinated neighboring fields resulting in cross contamination. Estimates for the financial loss resulting from this debacle range from 100 million to 1 billion US dollars; the USDA announced in March of 2001 that it would buy back 300,000-400,000 sacks of seeds at a cost to taxpayers of $15-20 million [7]. Consumer confidence in US raised corn both here and abroad remains shaken.

TESTING FOR GMOs

Identification of GMOs can be based on the presence of transgenic DNA, the transcribed mRNA, the resulting protein product or metabolite or on the basis of altered phenotype. In most cases GMOs are phenotypically identical to the parent organism hence the last option is not practicable. In general, detection of the transgenic DNA by polymerase chain reaction (PCR) methods or detection of the protein product by antibody based methods (such as an enzyme linked immunosorbant assay [ELISA] or Western Blot immunosorbant assays) are the most reliable methods [16]. ELISA tests are simple to perform, quite specific and are relatively inexpensive. These are the types of assays initially employed to find the StarLink contamination. However, to develop an immunosorbant assay one must first have access to the protein product in order to develop antibodies. This is not always feasible, particularly when screening for new products, proprietary products or to find suspected GMOs of unknown origin.

PCR based assays are the most widely used for the detection of GMOs. Transgenic genes require regions of DNA termed promoters immediately upstream from the target DNA to ensure efficient protein production and terminator regions immediately downstream to provide a stop signal for the transcription process. There are only a few such promoter and terminator sequences currently in use with transgenic plants. Because the sequences of these promoter and terminator sequences are known, PCR primers can be synthesized that will amplify these inserts thus providing evidence of their presence in the sample [17]. Other PCR methods can then be employed to identify the flanking regions of DNA. The polymerase chain reaction is an exquisitely sensitive analytical method. In theory only one copy of a target DNA sequence is necessary for detection. Nevertheless owing to the amount of DNA that can be introduced into a reaction vessel and the size of the plant's genetic material there is a theoretical lower detection limit of approximately 0.01%, i.e. if 1 seed in 10,000 contains a transgenic gene it can be detected. For technical reasons this lower limit is generally ascribed to be 0.1% [18,19].

FUTURE IMPLICATIONS

Biotechnology in the agricultural sciences is a reality. There is tremendous potential for the betterment of mankind offered by these technologies but there is also reason for concern. The StarLink fiasco is a case in point. The continuing debate on the merits and risks of GMOs is not likely to be resolved in the foreseeable future. What impact does this debate and the release of GMOs in the environment pose for the US Army?

The consequences of GMOs to the Army are likely to be quite subtle. Recalls of foods such as the StarLink case could impact on the general food supply. There is likely to be some genetic drift of herbicide and insecticide resistance that will potentially alter the habitat of military installations in unpredictable ways [20]. There is a possibility of deliberate contamination of export crops and processed foods to sabotage US trade relations with other countries either by deliberately planting GMO foods with the intention of being found or to attempt to bypass screening procedures thus introducing GMOs into countries previously free of these crops. One potential scenario might be a crop, such as soybeans, being engineered to produce a highly toxic compound and used to contaminate the nation's seed supply. Although not likely to result in mass casualties, the panic and economic consequences resulting from a single victim could be devastating.

The plight of third world countries struggling with food shortages cannot be ignored. Recently the government of Zambia refused relief shipments of US corn due to fears of contaminating the local crop with GMOs as well as the perception that the populous was being employed as "guinea pigs" for the development of Western technology. With burgeoning populations in the third world and increasingly stressed resources, the threat of war precipitating from basic needs such as food and water is ever present. The ideological riff between the US (and other GMO producing countries) with the EU over this issue continues to exacerbate this problem with unpredictable repercussions for U.S. military involvement. A more subtle effect, if the development of GMOs becomes politically unsavory to this country, is that many of the potential benefits will be lost or unreasonably delayed. As mentioned earlier, plants such as grasses can potentially be engineered to report the presence of various environmental contaminates. Employment of such technology to detect unexploded ordinance or other maleficent compounds on Army training ranges is not beyond reason. While much of the pioneering work on GMOs is conducted in research universities, the commercialization and militarization of these technologies will require the interest of private industry. If it

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becomes financially prohibitive to produce these organisms, due to excessive regulation, the necessary infrastructure will be lost.

Notes about the author:

MAJ Mitchell L. Wise is an Army Reserve Chemical Officer. He has held a variety of progressively more responsible assignments in the Active Army, US Army Reserves and the National Guard. He attended the Chemical School at Fort McClellan and Airborne Training at Fort Benning. In his civilian professional life, Dr. Wise holds a Ph.D. in Biochemistry/ Biophysics from Oregon State University. His earlier studies were in fisheries and environmental microbiology. Currently, a Research Biochemist with the United States Department of Agriculture, Agricultural Research Service at Madison, Wisconsin 53705, he conducts research on improving nutritive composition of grains. Dr. Wise investigates biosynthetic pathways to novel secondary metabolites with the objective of finding methods to manipulate their production in agricultural products.

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